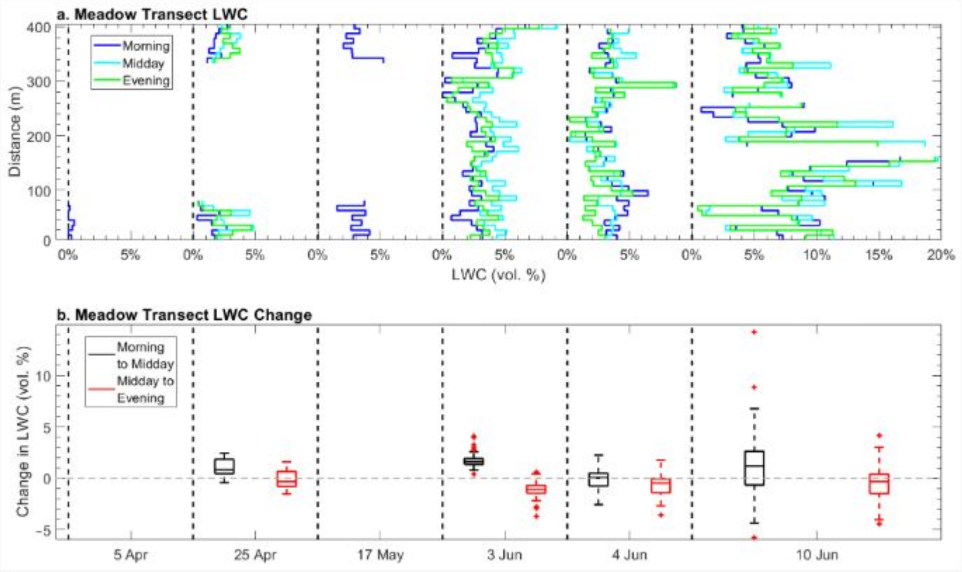
binary wet snow threshold localization

snow wetness is complicated

- when is snow wet??
  - LWC > 1% ?
  - 0C ?
- snow wetness is highly variable
  - temporally: LWC variability of ~5% subdaily! (Webb et al 2020, Monitoring a snowpack's ability to store liquid water at the small catchment scale)
  - spatially: LWC variability of ~5-10% over only 1m! (Webb et al 2018, Combining Ground-Penetrating Radar With Terrestrial LiDAR Scanning to Estimate the Spatial Distribution of Liquid Water Content in Seasonal Snowpacks)

Bonnell et al 2021

Figure 12. (**a**) Meadow Transect LWC averaged along 9 m intervals for morning, midday, and evening surveys, plotted with distance along transect. Explainable outliers were removed and are represented as breaks in the line. (**b**) Box plots of ΔLWC along the Meadow Transect from morning to midday and from midday to evening. Positive values represent an increase in LWC, and negative values represent a decrease in LWC.



papers of interest: radar remote sensing and LWC

R Magagi, M Bernier, Optimal conditions for wet snow detection using RADARSAT SAR data, Remote Sensing of Environment, Volume 84, Issue 2, 2003, Pages 221-233, ISSN 0034-4257, https://doi.org/10.1016/S0034-4257(02)00104-9

Bonnell R, McGrath D, Williams K, Webb R, Fassnacht SR, Marshall H-P. Spatiotemporal Variations in Liquid Water Content in a Seasonal Snowpack: Implications for Radar Remote Sensing. Remote Sensing. 2021; 13(21):4223. https://doi.org/10.3390/rs13214223

the problem with with binary wet snow detection

- for both active and passive binary wet snow detection, there are a ton of methods for thresholding (e.g. for SAR: -1dB to -2dB to -3dB, VV, VH, VV/VH combinations weighted on LIA, vegetation, different reference images, etc), but very little spatially distributed wetness data to validate against :(
    - true sub-pixel spatial snow wetness variability makes snow wetness detection complicated for SAR (S1 ~20m), even more complicated for passive microwave (~25km)
    - temporal resolution and sampling times of SAR (S1, 6/12 days same repeat dawn and dusk) + passive (2 times a day) makes it hard to capture temporal variability of snow wetness, especially diurnal
    - what do our instruments even measure??
        - S1 C-band in wet snow shouldn't penetrate more than 10cm

papers of interest: SAR binary wet snow

Nagler T, Rott H, Ripper E, Bippus G, Hetzenecker M. Advancements for Snowmelt Monitoring by Means of Sentinel-1 SAR. Remote Sensing. 2016; 8(4):348. https://doi.org/10.3390/rs8040348

Manickam S, Barros A. Parsing Synthetic Aperture Radar Measurements of Snow in Complex Terrain: Scaling Behaviour and Sensitivity to Snow Wetness and Landcover. Remote Sensing. 2020; 12(3):483. https://doi.org/10.3390/rs12030483

Lund J, Forster RR, Deeb EJ, Liston GE, Skiles SM, Marshall H-P. Interpreting Sentinel-1 SAR Backscatter Signals of Snowpack Surface Melt/Freeze, Warming, and Ripening, through Field Measurements and Physically-Based SnowModel. Remote Sensing. 2022; 14(16):4002. https://doi.org/10.3390/rs14164002

papers of interest: beyond binary… SAR -> LWC

Pettinato, S., Santi, E., Paloscia, S., Baroni, F., Pilia, S., Santurri, L., Palchetti, E., Bovenga, F., Belmonte, A., Refice, A., Argentiero, I., Colombo, R., Bramati, G., Di Mauro, B., Marin, C., Cuozzo, G., De Gregorio, L., Callegari, M., Heredia, M. S., … Montuori, A. (2023). Multi-Frequency SAR Images for Investigations of the Cryosphere: Preliminary Results of Criosar Project. IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium, 1585–1588. https://doi.org/10.1109/IGARSS52108.2023.10281448

papers of interest: SAR validation

Marin, C., Bertoldi, G., Premier, V., Callegari, M., Brida, C., Hürkamp, K., Tschiersch, J., Zebisch, M., and Notarnicola, C.: Use of Sentinel-1 radar observations to evaluate snowmelt dynamics in alpine regions, The Cryosphere, 14, 935–956, https://doi.org/10.5194/tc-14-935-2020

Lund, J., Forster, R. R., Jameel, Y., Rupper, S. B., Deeb, E. J., Dars, G. H., et al. (2023). Constraining mountain streamflow constituents by integrating citizen scientist acquired geochemical samples and Sentinel-1 SAR wet snow time-series for the Shimshal catchment in the Karakoram Mountains of Pakistan. Water Resources Research, 59, e2022WR032171. https://doi.org/10.1029/2022WR032171

Lila Rickenbaugh's work – soon to come!!

an idea for an empirical approach

- for a ratio image with wet snow, compare histograms of dB change values
    - compare dB drop within snow/no snow classes using optical imagery for snow/no snow classification (figure on the right from Nagler et al. 2016)
    - hopefully find bimodal distribution which would allow us to optimize a wet snow threshold
- then iterate at lots of locations with different landcover/veg, different snow classification types, snow depths, variable topography (to get at incidence angle dependence)
    - snow / no snow classes will be helpful here to pull out variable dB drop due to wet snow
- could either:
    - optimize a wet snow threshold for each scene
    - (i think this is more promising) build up a huge datacube of [VVdB drop,VHdB drop, snow/nosnow, LIA, LCC/veg, snowclass, where in the melt season are we, fSCA, othervars?] for each pixel at all locations, then optimize or use ML/DL approach
- will help us characterize how binary wet snow threshold changes with these variables allowing localization of this threshold
    - end goal would be some sort of heuristic: given a pixel with x vegetation/LC type, y snow class, z incidence angle, we expect at least a backscatter change of -XdB in VV and -YdB in VH from the reference image to the wet snow image
    - if it works, could be the foundation of a “smart” binary wet snow algorithm, where the binary wet snow threshold is variable across a scene as a function of [landcover class, snow class, local incidence angle, etc]

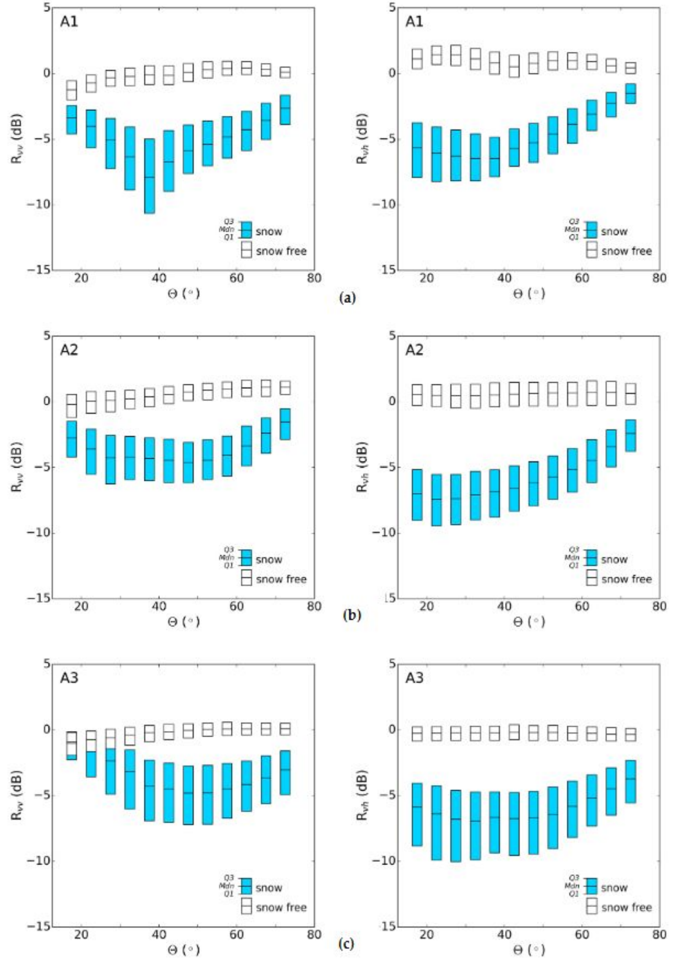


Figure 2. Backscatter ratio (median, Mdn, 1st and 3rd quartile) for S1 *VV*- and *VH*- polarized channels in dependence of the local incidence angle, θ, for areas classified as snow-free and snow-covered in Landsat images (see Section 3.2): **(a)** test site A1: Tröllaskagi; **(b)** test site A2: Ötztal Alps; **(c)** test site A3: Swiss Alps.

active + passive microwave idea

probably don’t have time to do something like this too, but interesting to think about and if we decide it’s worth pursuing, maybe we can loop in mahboubeh and angela?

papers of interest: passive validation

Ziqian Zhang, Lei Zheng, Wanchun Leng, Tianjie Zhao, Teng Li, Qi Liang, Xiao Cheng, Toward a real validation of passive microwave snowmelt detection algorithms over the Antarctic Ice sheet, International Journal of Applied Earth Observation and Geoinformation, Volume 125, 2023, 103600, ISSN 1569-8432, https://doi.org/10.1016/j.jag.2023.103600

Ramage, J.M., McKenney, R.A., Thorson, B., Maltais, P. and Kopczynski, S.E. (2006), Relationship between passive microwave-derived snowmelt and surface-measured discharge, Wheaton River, Yukon Territory, Canada. Hydrol. Process., 20: 689-704. https://doi.org/10.1002/hyp.6133

papers of interest: active + passive used together

Andrew Johnson, Mark Fahnestock, Regine Hock, Evaluation of passive microwave melt detection methods on Antarctic Peninsula ice shelves using time series of Sentinel-1 SAR, Remote Sensing of Environment, Volume 250, 2020, 112044, ISSN 0034-4257, https://doi.org/10.1016/j.rse.2020.112044

Sophie de Roda Husman, Stef Lhermitte, Jordi Bolibar, Maaike Izeboud, Zhongyang Hu, Shashwat Shukla, Marijn van der Meer, David Long, Bert Wouters, A high-resolution record of surface melt on Antarctic ice shelves using multi-source remote sensing data and deep learning, Remote Sensing of Environment, Volume 301, 2024, 113950, ISSN 0034-4257, https://doi.org/10.1016/j.rse.2023.113950

active + passive fusion: harmonizing thresholds

apples to apples: If we can't independently validate active and passive wet snow measurements, can we at least align thresholds so they identify the same wet snow (in the same area at the same time)?? this paper attempts to compare ice sheet melt in antarctica from active and passive. if we get threshold alignment here and then in more complicated snow covered areas, could provide important groundwork for those trying to fuse active and passive

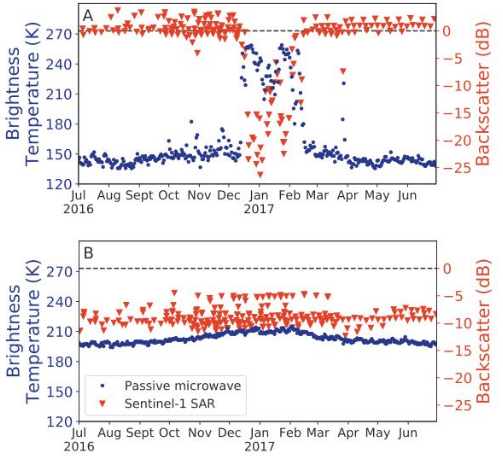


Fig. 1. Raw passive and active microwave measurements of two locations for July 2016 through June 2017. Passive measurements are taken from SSMIS at 19 GHz in the horizontal polarization. Backscatter data is from Sentinel-1C-band SAR in the HH polarization. (A) Point on Larsen C Ice Shelf that experiences summer melt (53 m a.s.l.). (B) Point on Antarctic Peninsula ice sheet that does not melt (1107 m a.s.l.). Locations of A and B are shown in Fig. 2.

Remote Sensing of Environment 250 (2020) 112044

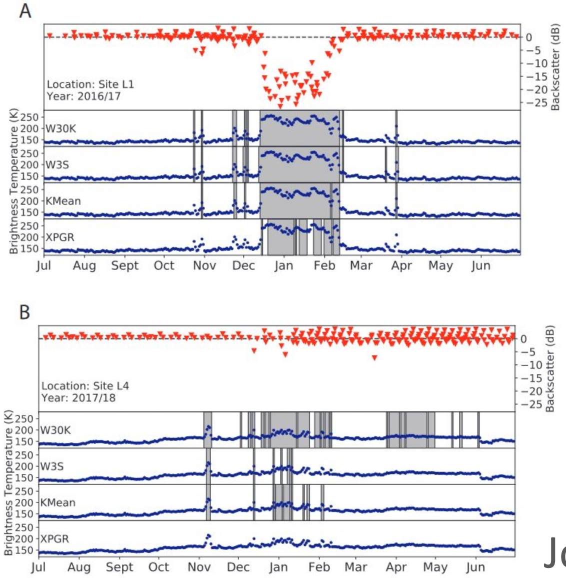


Fig. 3. Comparison of passive microwave (19 GHz horizontal, 25 × 25 km² pixel) and observed SAR (1 km² pixel) measurements at single location. Melt determinations from each of the four passive methods given by gray shaded regions. Small blue dots indicate brightness temperature, red triangles indicate backscatter. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Johnson et al 2020